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NATIONAL RADIO ASTRONOMY OBSERVATORY

Tucson, Arizona

1999 January 10

MEMORANDUM

To:	Peter Napier
From:	Larry D'Addario
Subj:	Pulse Tube Refrigerator Development—Decision Document
CC:	Darrel Emerson

The attached notes summarize the case for and against the development of a custom-designed pulse tube refrigerator (PTR) for use as part of the cryocoolers of the MMA receivers. It is possible, if we begin soon, to produce a design that meets our requirements and is ready for production on a schedule matching that of the other parts of the receivers. But doing so will require a substantial, immediate expenditure on an outside development contract. The effort would not be without risk, but this should be weighed against the significant advantages to MMA operation that would be achieved if it is successful.

A prompt decision on whether to proceed with this is requested of the MMA management.

DECISION DOCUMENT—PULSE TUBE REFRIGERATOR DEVELOPMENT

LRD, 1999-01-11

PROPOSAL: Allocate \$300k to an outside contract for the development of a cryocooler for the first two stages of the MMA receiver. Note that the budget proposed for all of cryogenics development in D&D was 396k\$ in May 1998, and this included 150k\$ for work similar to that proposed here. The present total allocation is 255k\$ (-36% from request). Support of this proposal requires restoring the original request (+141k\$) and adding another 150k\$. (Even if this proposal is not supported, the allocation should be increased by 91k\$ in order to allow other cryogenics development to proceed.)

3.5K

PURPOSE: To allow the use of a Sterling-style pulse tube refrigerator (PTR) for the first two stages of cooling (with a Joule-Thompson refrigerator for the third stage at 4K). Such refrigerators have important advantages as explained below. Technical requirements for the system are given in RFP MMA1-98, which should be read and understood by anyone involved in evaluating the present proposal.

COST AND DELIVERABLES: In RFP MMA1-98 (issued Nov 1998 with proposals received and evaluated in Dec 1998), we requested fixed price bids for a development program leading to delivery of a full prototype in 18 months, ready for production, with performance guaranteed in advance. Three technically sound proposals were received, but the RFP structure proved to be so stringent that all of them were far too expensive (587k$ to 1380k$). After discussions with two of the proposers, we now believe that a meaningful but reduced-scope effort can be funded for $300k (see letter from Radebaugh to D'Addario, 1999 Jan 06). This would allow design, simulations, and laboratory experiments leading to a laboratory model in 18 months. After 12 months and about $200k, all existing design uncertainties should be resolved, and the project could be terminated if results are not satisfactory. Cost savings compared with the RFP bids result from (a) combining NRAO's funding with that from other agencies (DARPA and NASA) interested in similar work; (b) not requiring that performance be guaranteed in advance; and © not requiring that NRAO own the resulting laboratory model, some parts of which will be the property of other agencies. If this system is selected for use on the MMA, an additional engineering effort would be needed to prepare the design for volume production.

ALTERNATIVES: If the proposed effort is not pursued, viable alternatives for the MMA include: (a) Use a Gifford-McMahon (GM) cryocooler for the first two stages, as has been done traditionally. This technology is more than 20 years old and involves many life-limited parts. Using the most reliable commercial model known to us (CTI 350), an MMA with 72 cryocoolers will require that one be overhauled every 10 days. A large stock of spares will be needed to buffer the overhaul work. Random failures of cold heads will typically cause several antennas to be out of service at any time; compressor and plumbing failures may increase this. (b) Use a GM cryocooler that reaches 4K in two stages, eliminating the JT stage. Such refrigerators are available, but they have not been thoroughly tested for cooling SIS mixers. They are thermally inefficient and may produce unacceptable temperature modulation and vibration at 4K. Reliability is not accurately known. © Rely on developments in government and industry that occur between now and our final decision point without funding by us. In this case, we continue to monitor those developments closely with the intention of selecting an off-the-shelf product in about 2 years.

SCHEDULE: Completion of a laboratory prototype in 2000/07 and of its thorough testing in 2000/12 allows plenty of time for its integration into the prototype receiver by 2002/03 (per R. Simon's schedule dated 1998/11) and its release for production along with the rest of the receiver by 2002/10. Indeed, considerable slack time is available. In case of difficulties, decision points at 2000/01 (completion of design studies), 2000/07 (completion of lab model), and 2000/12 (completion of testing) would allow the program to be discontinued and an off-the-shelf alternative selected without impact on the overall project schedule.

ADVANTAGES:

1. The principal advantage is much greater reliability and reduced maintenance. The PTR envisioned here has no moving parts in the cold head, and no life-limited parts anywhere (including the compressor). The system contains no oil and no rubbing parts, so there is little chance of contamination. Similar systems have been run continuously for five years with no maintenance. Whereas the compressor can have any orientation, no flexible hoses around the antenna axes are needed; these are also life-limited and have been a major reliability problem

on some NRAO antennas. Plumbing runs are short, with few connectors and reduced chance of leaks.

2. There is no cold-head vibration, since only a column of gas is moving.
3. Temperature modulation over the refrigeration cycle should be much better damped because the expected operating frequency is ~30 Hz vs. ~2 Hz for GM. Spectrum?
4. Power efficiency is much better than GM. Line power is predicted to be 800 to 1100W, compared with 1800W for GM of similar cooling power. This produces lower total heat dissipation, producing smaller total volume and other such secondary advantages.

DISADVANTAGES:

1. Production cost of a flexure-bearing linear compressor will be higher than for the rotary compressors usually used with GM refrigerators, primarily because the latter are in high-volume production. The cold head cost of the PTR should be lower because of its inherent simplicity. Overall, the per-system cost is estimated at 28k$ for the PTR vs. 12.5k$ for a similar-sized GM. (The 300k$ development cost is small if amortized across ~80 systems.) This may get better by the time we need to begin production because this type of compressor may become popular for other applications.
2. There may be significant orientation dependence of the refrigeration capacity. Available data indicates that this should be negligible for a +-45deg range around optimum, and will probably be better at the operating parameter values planned for us. If orientation dependence is found to be significant, the worst effect is that it produces inconvenient mechanical constraints for integration with the receiver.
3. The compressor should be located as close as possible to the cold head, and may need to be integrated with the dewar assembly. Whereas space there is critical, this is inconvenient. Present estimates of size indicate that it will fit without difficulty, but close coordination is needed in mechanical design of receiver and refrigerator. Vibration?

RISKS:

The following descriptions of the possible risks in this effort are followed by my subjective assessment of the probability of each. Since these probabilities have little objective basis, they should be used only as rough indicators.

1. Perhaps the desired performance will not be achieved within the available time because of unforeseen basic problems; i.e., the technology is not sufficiently mature. Estimated probability: 10% now, 5% after successful 1-year design phase, zero after successful laboratory model tests.
2. Perhaps the effort required to transform a successful laboratory model into a design suitable for production will be costly and will delay the project. Est prob: 10%.
3. Perhaps the production models will have unexpected flaws that produce unreliable operation, negating the expected advantages. Est prob, given success in all work leading up to production: 2%.

4. Perhaps our present estimate of the required cryocooler size is not sufficient, and thus even if the planned development is successful it cannot be used for the MMA production receivers. Est prob: 10% now, zero after further in-house studies in CY1999.